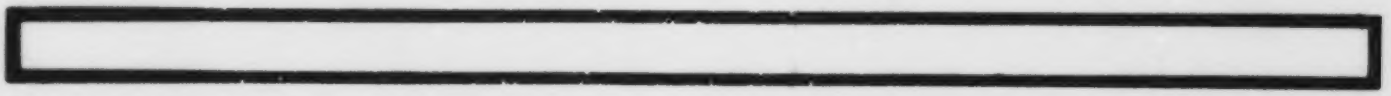
PB84-177492

Improved Technique for Estimating Mean Depths of Lakes

(U.S.) Corvallis Environmental Research Lab., OR

1983



U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before comple

1. REPORT NO.	2.	3
EPA-600/J-83-195		PB84-177492

4. TITLE AND SUBTITLE
An Improved Technique for Estimating Mean Depths of Lakes. (Journal Version)

5. REPORT DATE
1983

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
James M. Omernik and Andrew J. Kinney

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Environmental Research Laboratory
Office of Research and Development
U.S. E.P.A.
Corvallis, Oregon 97333

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Same

13. TYPE OF REPORT AND PERIOD COVERED
Journal Article

14. SPONSORING AGENCY CODE
EPA/600/02

15. SUPPLEMENTARY NOTES
Published in: Water Res. Vol. 17, No. 11, pp.1603-1607, 1983

16. ABSTRACT

We describe a technique for determining mean lake depth utilizing a systematically aligned dot grid. This technique is, on the average, 55% faster than the traditional planimeter methods, depending on the type of planimeter and the size and complexity of the lake. No detectable bias is associated with results from this technique compared with those of traditional planimeter methods. The relationship $N_p = \sqrt{A}$, where N_p= the number of dots falling within the shoreline of the lake and A= the surface area of the lake in ft^2, gives a quick estimation of the number of dots that should fall within the shoreline boundary of a lake for optimum sampling.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to Public	Unclassified	6
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA-600/J-83-195
JOURNAL VERSION

Water Res. Vol. 17, No. 11, pp. 1603–1607, 1983
Printed in Great Britain. All rights reserved

0043-1354/8
Copyright © 1983 Pergamon Press Ltd

AN IMPROVED TECHNIQUE FOR ESTIMATING MEAN DEPTH OF LAKES

JAMES M. OMERNIK and ANDREW J. KINNEY
U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory,
200 S.W. 35th Street, Corvallis, OR 97333, U.S.A.

(*Received January* 1983)

Abstract—We describe a technique for determining mean lake depth utilizing a systematically aligned dot grid. This technique is, on average, 55% faster than the traditional planimeter methods, depending on the type of planimeter and the size and complexity of the lake. No detectable bias is associated with results from this technique compared with those of traditional planimeter methods. The relationship $N_D = \sqrt[4]{A}$; where N_D = the number of dots falling within the shoreline of the lake and A = the surface area of the lake in ft^2, gives a quick estimation of the number of dots that should fall within the shoreline boundary of a lake for optimum sampling.

Key words—lakes, bathymetry, lake depth, lake measurement, mapping, lake morphometry

INTRODUCTION

Mean depth of lakes continues to be an important morphometric parameter in thermal modeling and in studies relating lake sensitivity to nutrient loading (Hutchinson, 1938; Rawson, 1952; Wetzel, 1975). The National Eutrophication Survey (NES) conducted by the U.S. Environmental Protection Agency developed nutrient budgets for 775 lakes and reservoirs in the conterminous United States. Determination of mean depth of many of these water bodies was one of the necessary tasks; but, because of the large number of lakes involved, use of the traditional method to make the determination appeared unnecessarily time consuming. Instead, an alternative method was employed in which transparent equidistant or dot grid patterns were utilized to calculate mean depth.

A review of the literature on limnological methods disclosed several procedures for calculating mean depth of lakes based on first obtaining the volume of the lake, then dividing by the lake surface area to obtain the mean depth (Welch, 1948; Lind, 1974; Hutchinson, 1975; Wetzel, 1975). Probably the most common procedure includes planimetering the area of the lake circumscribed by successively deeper contours and calculating the volume of each segment using the following formula:

$$V_{M-N} = \tfrac{1}{3}(M - N)(A_M + A_N + \sqrt{A_M A_N}) \quad (1)$$

where M = depth of the lower contour surface, N = depth of the upper contour surface, A_M = area of contour M and A_N = area of contour N. The V_{M-N} values are then summed and divided by total area to obtain the mean depth (Lind, 1974; Hutchinson, 1975). Olson (1960) presented a method, similar to the dot grid technique used by NES, which is based on a square lattice superimposed on a lake map. Olson believed this method's advantages to be that the precision of the measurements could be estimated, and that the method is simpler, faster, and required no special instruments. Wood referred to a technique similar to the one utilized by NES as a "dot planimeter" (Wood, 1954).

This paper describes the dot grid method for determining lake mean depth and compares the speed, precision and potential bias with traditional planimeter methods.

METHODS AND RESULTS

We compared two methods of estimating mean depth. Method I used the traditional planimeter approach utilizing two types of planimeters: (a) an electronic fixed-arm planimeter with a point needle tracer head; and (b) a compensating polar planimeter with a magnifying concentric circle lens tracer head. They are referred to as method Ia and method Ib, respectively. Calculating mean depth utilizing Methods Ia and Ib was accomplished by using equation (1). Method II consisted of randomly placing a systematically aligned or grid dot pattern over the bathymetric lake map (Fig. 1). We estimated the depth corresponding to each dot falling within the shoreline of the lake by visually interpolating between the contour lines. Dots falling on the shoreline were interpreted to be either slightly within or outside the shoreline. The depth readings were recorded, summed, and the total divided by the number of dot readings recorded to obtain the mean depth of the lake. Differences in map scale, and lake size and complexity, necessitated the use of different dot grid spacings.

In order to compare the variations within and between the methods, the mean depth for each lake was calculated three times by each method and for

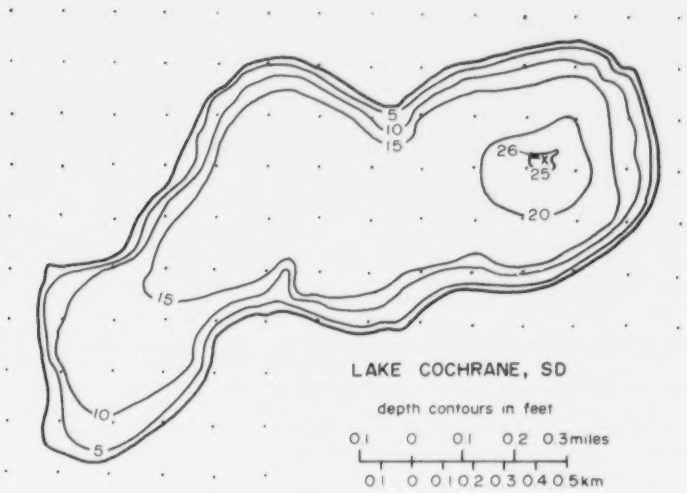


Fig. 1. A example of a systematically aligned dot grid superimposed on a bathymetric map.

each grid spacing used in Method II. Each single mean depth calculation was termed a trial. To allow for comparison in the amount of time required by each method, all trials were timed.

We selected lakes which would present a spectrum of morphometric and cartographic conditions so that possible limitations of the various methods could be determined (Table 1). The lakes are listed or ranked by complexity, with Hancock Lake being the simplest and Lake Mendota being the most complex. Complexity was determined by comparing shoreline diversification, maximum depth, bathymetric complexity, map scale, contour interval and contour spacing.

To aid in comparing method II to Methods Ia and Ib, we determined if an optimum number of dots per lake existed for estimating mean depth. To do this, we calculated mean depth by Method II using grid spacings of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.2, 1.4, 1.6, 1.8 and 2.0 in. Not all grid spacings were used on all lakes. Lakes such as Hancock and Silver would have had only one or two sample points at grid spacings greater than 1.4 in and lakes like Shagawa and Mendota would have had well over 500 sample points at grid spacing less than 0.5 in.

To determine if there was an optimum number of dots (sample points) per lake needed for calculating mean depth by Method II, we plotted the standard deviation of the three trials at each grid spacing against the number of dots used at that grid spacing (Fig. 2). It was clear that at low dot densities the standard deviation fluctuated much more and tended to be higher than at higher dot densities. As the number of dots per unit of lake surface area increased, the standard deviation stabilized, suggesting a point of diminishing returns. This apparent point of diminishing returns probably is largely controlled by the surface area of the lake. Other factors, principally bathymetric complexity, contour interval, and contour spacing, may also be important. The relation $N_D = \sqrt[4]{A}$; where N_D = the number of dots falling within the shoreline of the lake and A = the surface area of the lake in square feet, seems to provide a quick estimate of the point of diminishing returns (Fig. 2). The N_D values (Fig. 2) were consistently located after the oscillations in the standard deviation stabilized—the apparent point of diminishing returns. Therefore, the grid size containing, or closest to containing the number of dots estimated as optimum by the relation $N_D = \sqrt[4]{A}$ was used for trials of method II in this study.

In order to compare methods and determine possible patterns of differences, percent differences were plotted. Generally the percent difference between methods did not exceed 2% (except for Maude Lake and Vernon Lake), nor did one method produce

Table 1. Lake description

Lake name	State	Shape	Contour interval (ft)	Contour spacing	Max. lake depth (ft)	Map scale
Hancock	WA	Elliptical	Uneven	Large	22.5	1:14,400
Silver	WA	Circular	5	Small	22	1:9600
Harts	WA	Circular	10	Small	55	1:10,800
Cochrane	SD	Elliptical	5	Large	26	1:4788
Elbow	MN	Subrectangular	5	Large	20	1:7920
Maude	MN	Irregular	5	Medium	26	1:3960
Buffalo	MN	Circular	5	Large	32.5	1:7920
Vernon	LA	Dendritic	5	Small	52.5	1:31,680
Shagawa	MN	Irregular	5.3	Medium	46	1:11,000
Mendota	WI	Irregular	5	Medium	82.5	1:24,000

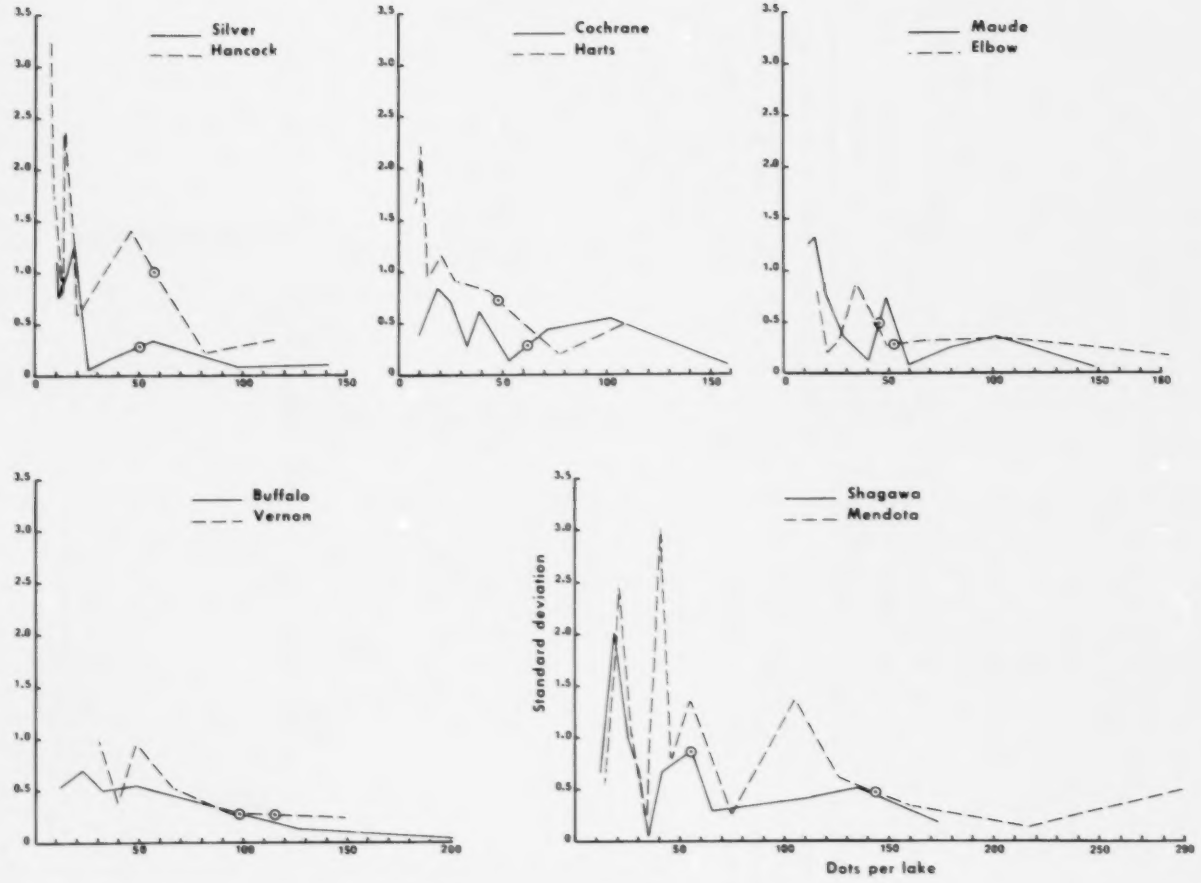


Fig. 2. Standard deviation at a given number of dots determined by dot spacing. The lakes were paired on graphs according to complexity, Silver and Hancock being the simplest and Shagawa and Mendota being the most complex. The symbol ⊙ indicates the values obtained from the relation $N_D = \sqrt[4]{A}$ where N_D = number of dots within the shoreline of the lake and A = surface area of the lake in ft^2.

consistently higher or lower values than another method (Fig. 3). A paired difference test confirmed these results. The paired-difference test determines whether the average difference between methods differs from zero; a statistically detectable difference suggests one method is biased relative to another (Snedecor and Cochran, 1978). For each comparison of pairs (Ia vs Ib, Ia vs II and Ib vs II), no bias was detected ($P = 0.05$).

There are likely reasons for the large deviations for Maude and Vernon lakes. Because Maude Lake is a small lake on a large scale map, the area measurements of contour intervals needed to be done in quarter sections when using the compensating polar planimeter of Method Ib; thus, there was a greater chance for error or deviation in the mean depth calculated by Method Ib than by either Method Ia or II. This is shown by the greater percent difference when comparing Method Ia to Method Ib and method Ib to Method II. When Method Ia and Method II are compared there is a negligible difference in mean depth values obtained. Conversely, Vernon Lake is a large lake on a small scale map. In this case our electronic planimeter could not accurately measure the area of the contours with small spatial extent; therefore, we obtained a higher percent difference when comparing method Ia with either methods ib or II and a negligible difference when comparing method Ib with Method II.

As a means of checking method II, we also conducted the same analyses using the Method II mean depth values obtained from the grid spacing trials with the greatest standard deviation (Fig. 2). Again, no differences between the mean depth values obtained by Methods Ia, Ib and II were evident. The average percent difference increased slightly to 3%, with Maude Lake and Vernon Lake showing the same patterns. Therefore, any reasonable number of dots can be used to estimate mean depth, but we still recommend using the equation $N_D = \sqrt[4]{A}$ for a probabe best estimation of the number of sample points to use. From these comparisons and tests, we believe that the use of the dot grid is valid and is as accurate a technique for estimating lake mean depth as are traditional methods.

Comparison of the time required for all trials for each method revealed the dot planimeter to be considerably faster than either the compensating polar or the electronic planimeters for determining mean depths of lakes. The percent time saved by using method II vs methods Ia and Ib is presented in Fig. 4. As in the preceding graphs, the lakes are

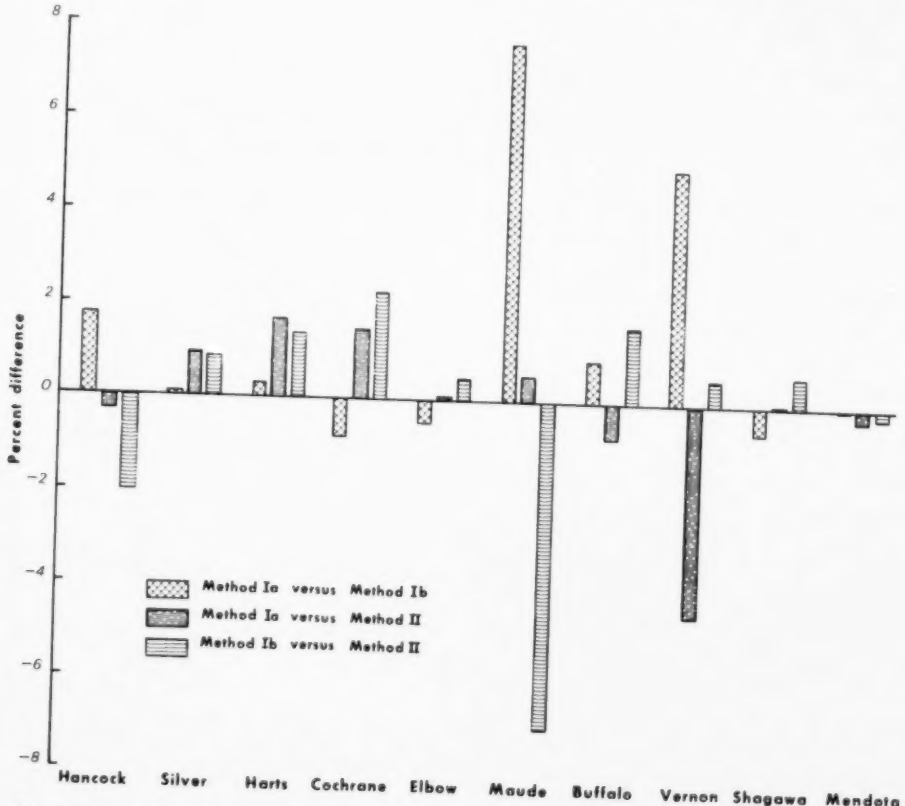


Fig. 3. Paired difference analysis shows the percent difference between the mean depths calculated by the various methods.

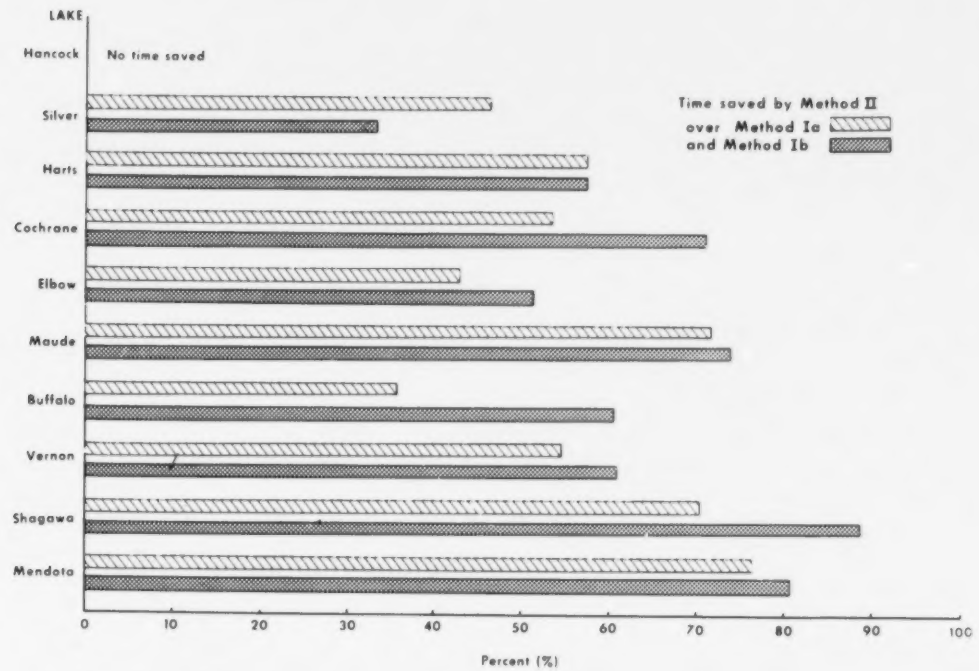


Fig. 4. Percent time saved by using Method II over Methods Ia and Ib. No time was saved when calculating mean depth for Hancock Lake due to its simplicity (only having two contour lines) when using the planimeters of Methods Ia and Ib, and its complexity (irregular contour interval) which complicates interpolations used in method II.

ranked according to complexity. Hancock Lake shows no time savings because of its simplicity, having only two contour intervals and an uneven contour spacing which makes interpolations in the dot method harder. Figure 4 illustrates that, in general, as lake complexity increases the amount of time saved by method II also increases. It also can be seen that method Ia, the electronic planimeter, is slightly faster than method Ib, the compensating polar planimeter.

Although all of the measurements included in this paper were made by one person, timed trials of mean depth measurements of most of the lakes were made by two other persons with very little difference in results. Generally, time per calculation decreased as the operator became more familiar with each method of planimetry. Therefore, all reported measurements were made after thorough familiarization with the methods tested.

CONCLUSIONS

We believe that a dot grid can be used to estimate mean depth with up to an 88% time savings and no bias when compared to traditional planimeter methods. Additionally, the dot grid technique requires a relatively routine arithmetic process and no mechanical devices. Factors affecting utility of the dot grid for estimating mean depth are: (1) the user's ability to interpolate values; (2) contour interval (the greater the interval or spacing between contours, the greater the chance for error in interpolation); and (3) map scale. Certainly, map scale should be consistent with lake size; but, in general, the larger the map scale the greater the level of detail represented, hence the greater the utility of the dot planimeter.

REFERENCES

Hutchinson G. E. (1938) Chemical stratification and lake morphology. *Proc. natn. Acad. Sci.* **24,** 63–69.

Hutchinson G. E. (1975) *A Treatise on Limnology—Geography and Physics of Lakes*, 2nd Edition, 1015 pp. Wiley, New York.

Lind O. T. (1974) *Handbook of Common Methods in Limnology*, 553 pp. C. V. Mosby Co., St Louis, MO.

Olson F. C. W. (1960) A system of morphometry. *Int. hydrog. Rev.* **37,** 147–155.

Rawson D. S. (1952) Mean depth and the fish production of large lakes. *Ecology* **33,** 515–621.

Snedecor G. W. and Cochran W. G. (1978) *Statistical Methods*, 6th Edition, 350 pp. The Iowa State University Press, Ames, IA.

Welch P. S. (1948) *Limnological Methods*, 538 pp. Blakiston Co., Philadelphia, PA.

Wetzel R. G. (1975) *Limnology*, 743 pp. W. B. Sanders, Philadelphia, PA.

Wood W. F. (1954) the dot planimeter, a new way to measure map area. *Prof. Geogr.* **1,** 12–14.